



Global Precipitation Measurement Mission Launch and Commissioning

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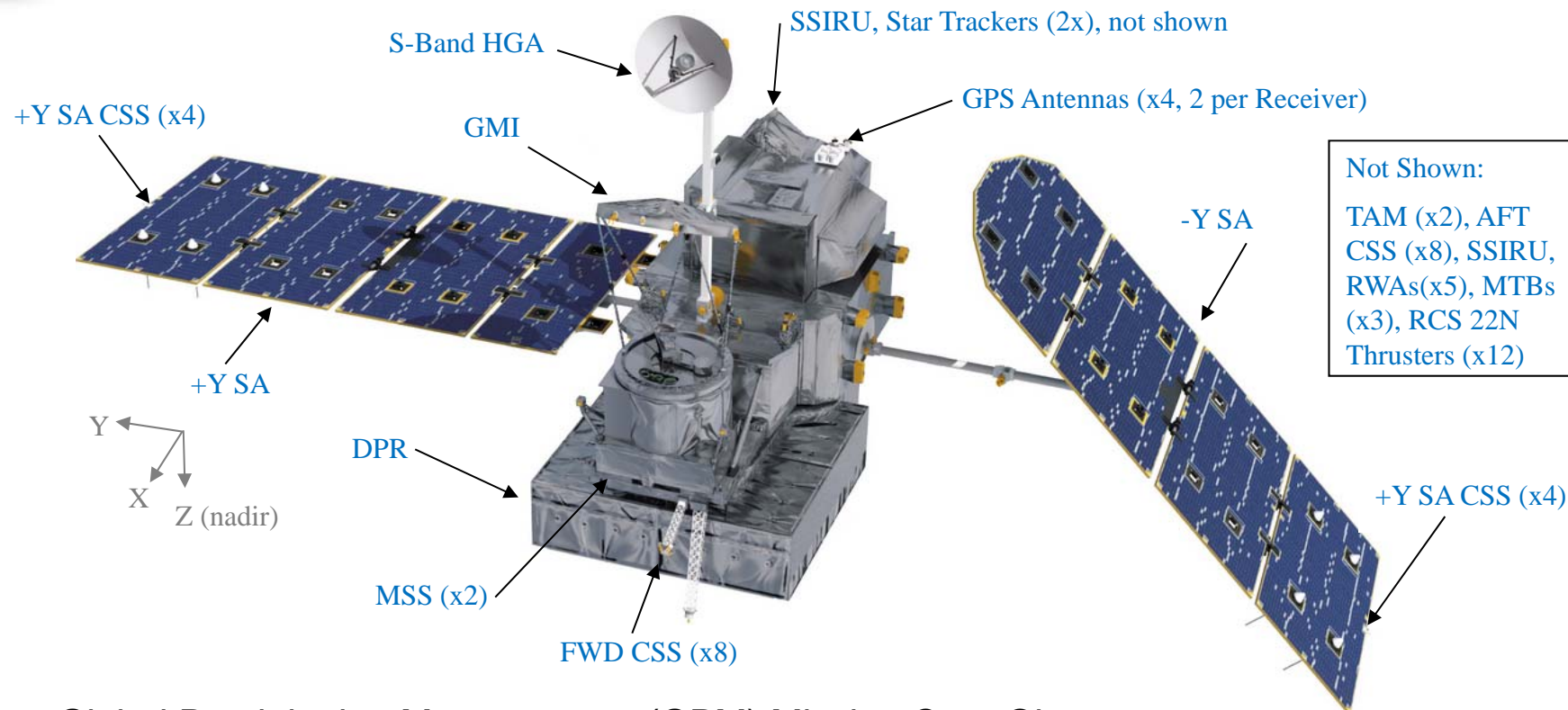
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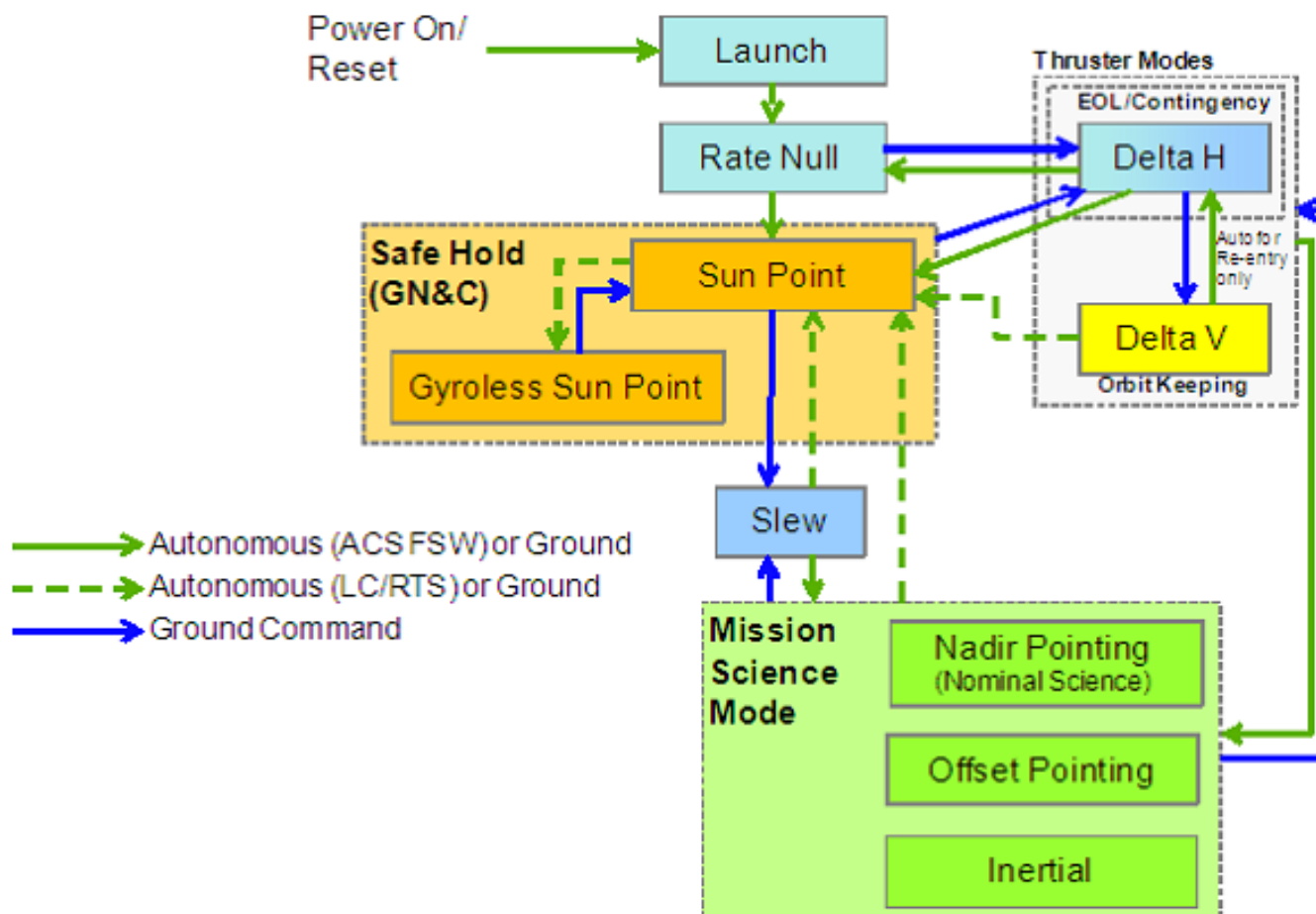
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- **Introduction**
 - **Description of GPM mission**
- **Post-Launch Activities and Flight Anomalies**
 - **Solar Array (SA) Deployment Dynamics**
 - **Angular Momentum Build-up**
 - **Sun Vector Discrepancy**
 - **Delta Quaternion**
- **Conclusion**
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- **Acknowledgements**
- **Questions**



- Global Precipitation Measurement (GPM) Mission Core Observatory
- Joint project between NASA and the Japanese Aerospace Exploration Agency (JAXA)
- Part of an international constellation of Earth Science Missions
- Instruments onboard include GPM Microwave Imager (GMI) and Dual-Frequency Precipitation Radar (DPR)
- Equipped with a Fault Detection & Correction (FDC) system to ensure spacecraft safety



- GPM has a total of 6 spacecraft control modes:
 - Rate Null Mode (RNM)
 - Sun Point Mode (SPM) or Gyroless Sun Point Mode (GSP)

- Delta V Mode (DVM)
- Delta H Mode (DHM)
- Slew Mode (SLM)
- Mission Science Mode (MSM)

*MSM is used for collecting science data



- GPM launched successfully on February 27, 2014 from Tanegashima Space Center located on the Japanese island of Tanegashima, Japan
- Shortly after liftoff, early checkout activities began, which included powering and verification of all on-board hardware systems and models
- Overall, the GN&C subsystem performed well during the first few days of the mission, however there were 4 anomalies identified that will be discussed in this presentation
- Ten days after launch, GPM was able to capture first of its kind images of precipitation inside a cyclone over the North West Pacific Ocean
- It is currently on orbit, collecting groundbreaking scientific data

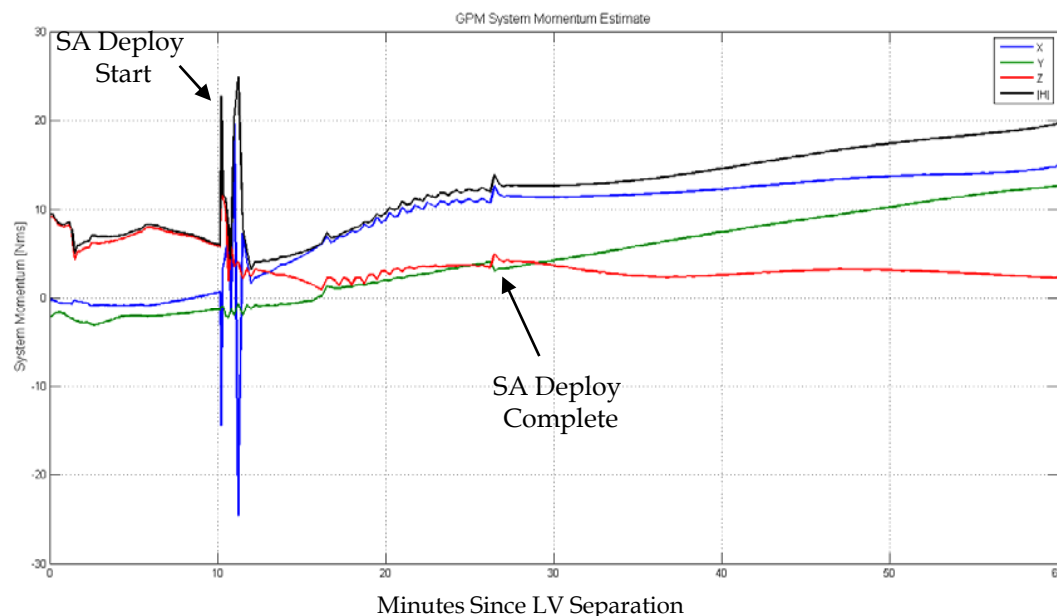


Spacecraft Launch Timeline



February 27, 2014 (GMT 058)-GPM Launch Activities

- GMT 18:37- GPM Liftoff on Japanese H-IIA rocket!!
- 18:41 - Fairing separation
- 18:47 - Acquisition of Comm
- 18:53 - Separation confirmation
- 18:54 - Reaction Wheels (RWA) powered
- 18:55 - Rate Null Mode (RNM) initiated
- 18:56 - Sun Point Mode (SPM) initiated
- 19:03 - Solar Arrays (SA) deployed
- 22:15 - Star Tracker (ST) A powered
- 059/01:04 - HGA deployment
- 01:15 - Confirmed HGA deployment
- 01:50 - ST-B powered
- 02:14 - Navigator B powered
- 02:18 - Navigator A powered
- 06:00 - GN&C checkout complete
- 12:25 - Slew to Mission Science Mode
- 073/00:44 - GMI powered



Issue:

- A rapid increase in spacecraft total system angular momentum was autonomously detected
- On-board FDC triggers if the system momentum magnitude difference is greater than 5Nms for 3 consecutive cycles (300ms), and takes actions to send the spacecraft to Sun Point Mode

Actions taken:

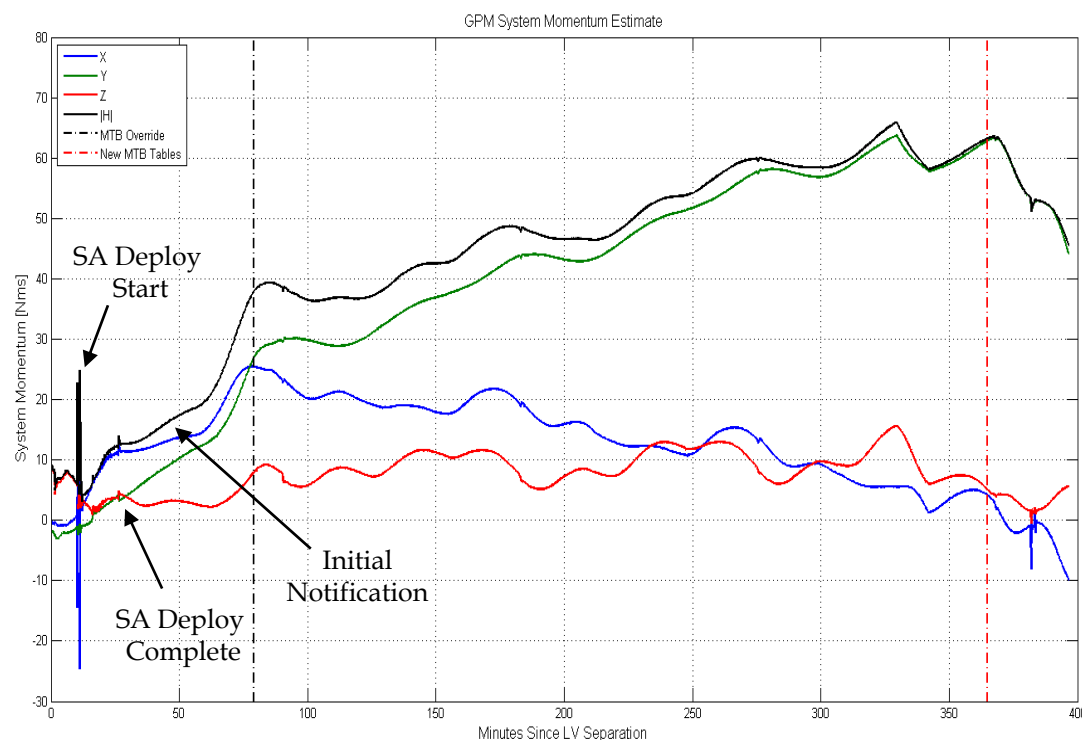
- Event reconstruction was difficult due to a limited bandwidth and downsampling for storage space (5 second data storage rate)
- When enough data was collected, engineers observed large jumps in the estimated system momentum at separation +610 seconds and separation +655 seconds
- There was enough circumstantial evidence to conclude that the system responded to the unexpected large torques on the body due to the initial dynamics from the non-explosive actuator firings and solar array deployment₇

Issue:

- After separation from the launch vehicle, deployments, and Sun acquisition, engineers observed a slow system momentum increase for GPM

Actions taken:

- Approximately 90 minutes into the mission, an anomaly was declared and the MTB current drive was overridden to zero while new software tables were being prepared for upload
- Once the MTB current was overridden, the rate of momentum growth noticeably decreased, giving the engineers on console more confidence of the source of the problem
- A new flight software table was generated that negated the orientation of the MTB axes in the body frame
- An investigation into the cause of the phasing issue determined that the anomaly occurred because of incorrect assumptions about the field direction as stated in the MTB documentation coupled with an incorrect understanding of the ground test magnetometer instrument



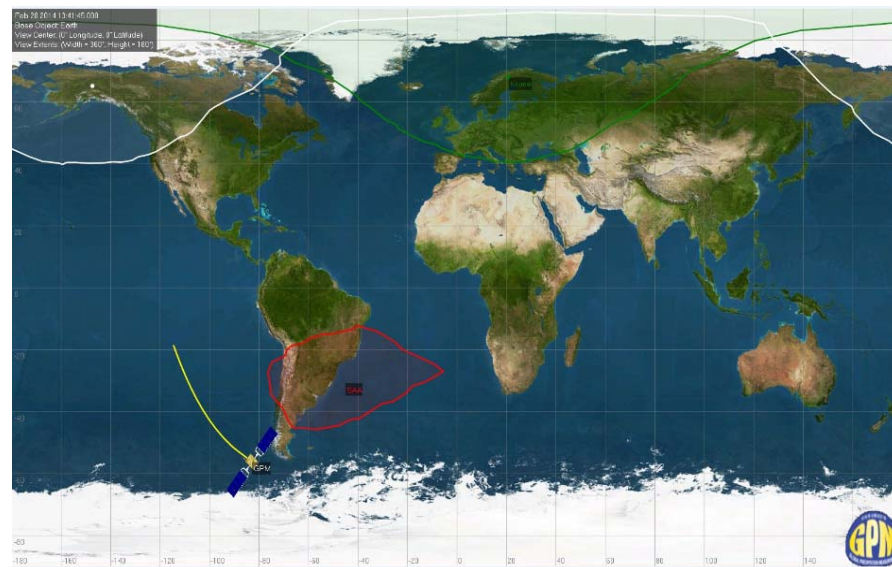
Issue:

- The spacecraft was unexpectedly sent from Mission Science Mode (MSM) to Sun Point Mode due to an FDC check
- The check compared the Sun vector calculated using the Coarse Sun Sensors against the Sun vector calculated using the on-board models (OM) Sun vector and estimated attitude from the Kalman Filter (KF)

Actions taken:

- GN&C engineers checked out the hardware and confirmed that everything was performing nominally
- The decision was made to passivate that particular FDC, transition the spacecraft back to MSM, and continue with the investigation as to why that particular FDC failed
- Once back in MSM and nadir tracking, it was observed that the particular FDC continued to exceed limits every orbit around the same point in the orbit ground track

- The Sun angle error FDC was observed to trip right above the coast of Antarctica
- The premise was then that the reflection of the Sun on the snow and ice was causing the CSS Sun vector to have a larger error
- Using data collected over several months, the GN&C team suggested increasing the angular error limit to 30 degrees and the persistence to 5 minutes

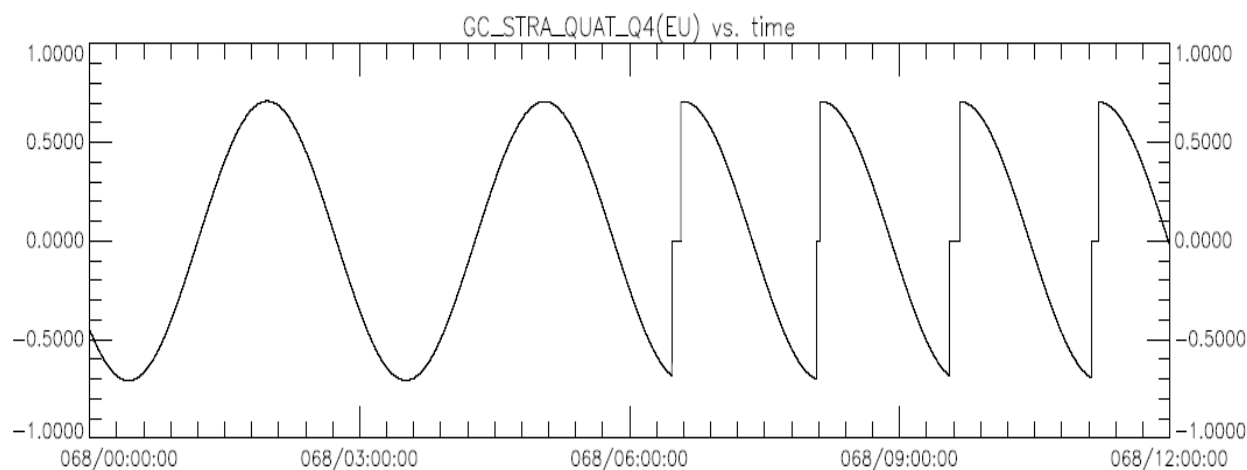


Issue:

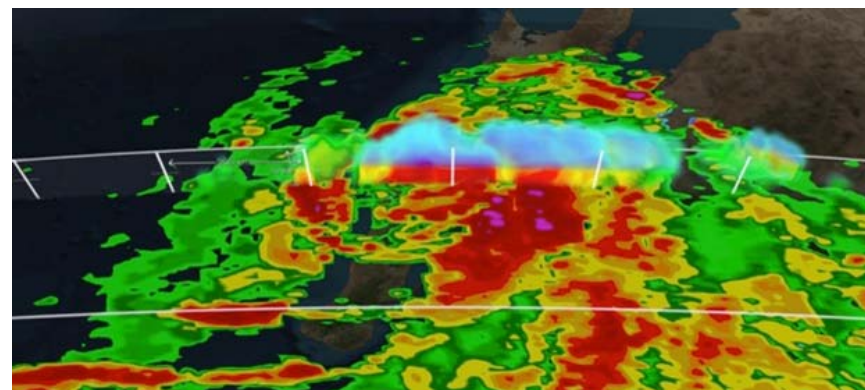
- The spacecraft entered a period where the Star Tracker (ST) was being occulted by the moon every orbit, causing it to fall out of track mode
- Upon reacquisition of ST data each orbit, the KF related FDC check on the delta quaternion between the gyro-propagated attitude solution and the ST-based attitude solution tripped
 - Per the FDC design, if that test failed a second time, the s/c would be sent to Sun Point Mode
- FDC check failed because the delta quaternion calculation did not enforce Q4 positive
 - When ST reenters track mode, measured quaternion starts with a positive Q4
 - However, gyro propagated ECI-to S/C quaternion would continue with its prior polarity

Actions taken:

- Ops manually reset the check every orbit until:
- RTS used to repromote the ST back to track mode was augmented to reset the KF 10 seconds after re-promoting the ST to track mode
 - Resetting the KF resynched the propagated solution with the ST solution
- Final solution was to patch the FSW to enforce Q4 positive in the delta quaternion calculation



- All anomalies were successfully mitigated before any damage to the spacecraft or science instruments
- May 29, 2014, the Core Observatory was handed over to the Mission Flight Operations Team at Goddard Space Flight Center for future commanding
- GPM is bringing improved data to scientists around the world. It was able to observe hurricane Odile on September 15, 2014 as it made landfall in Southern California and Western Mexico. This was a severe tropical cyclone, sustaining winds up to 125 mph. GPM was able to capture detailed images including frozen precipitation (shown in blue) above melting layer



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Questions?